Large Detectors on Small Telescopes

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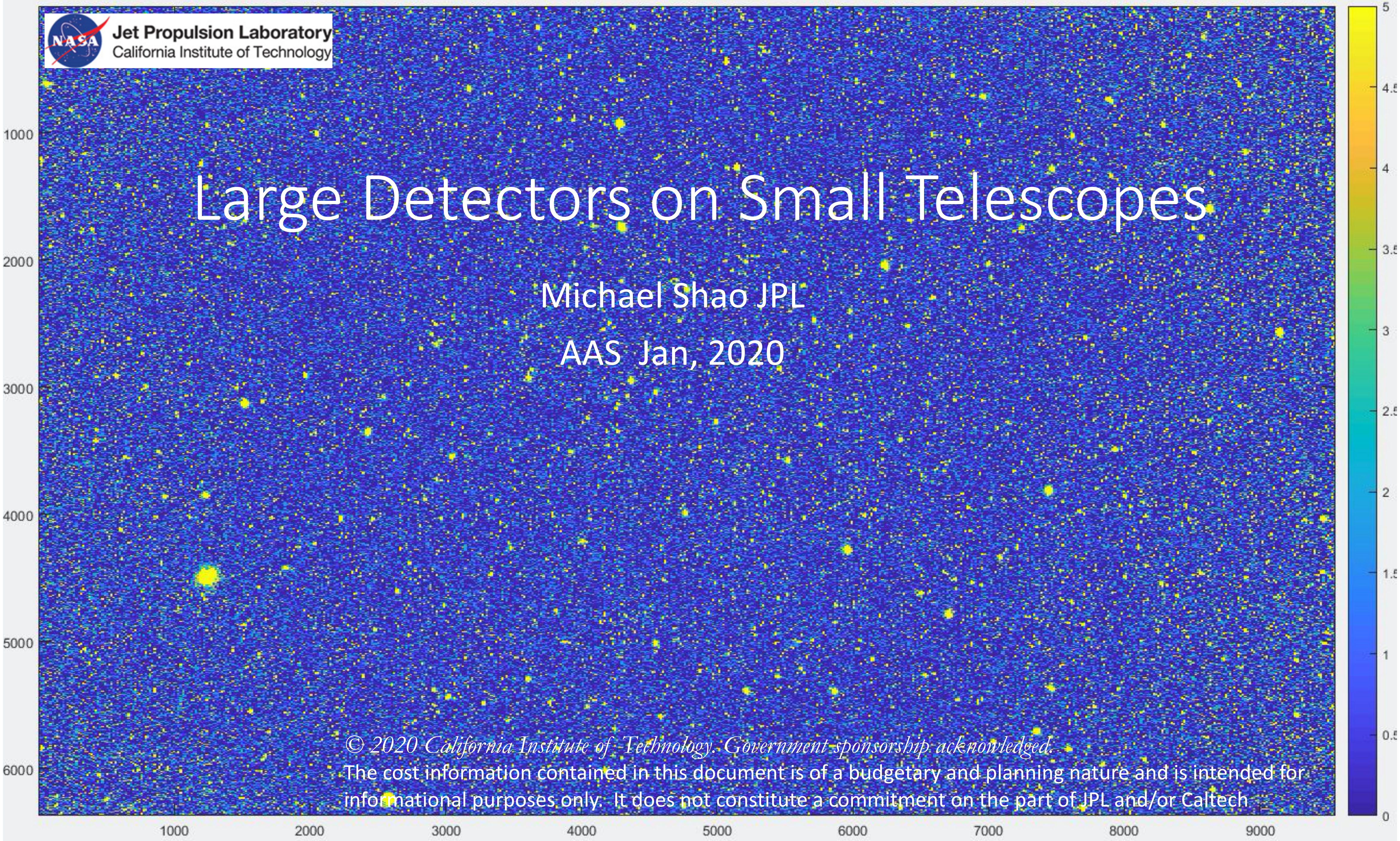


New Sensors Change the Cost Scaling of Survey Telescopes

- Survey telescopes have as a figure of merit A*Ω, area*solid angle product
  - Panstars, ZTF, Catalina Sky Survey,
  - LSST 6.5m equiv aperture 9.2 sqdeg FOV 3.2Gpix focal plane
- Small consumer telescopes
  - 11 inch RASA (28cm Dia, f/2.2, 4deg dia FOV)
  - 14 inch RASA (36cm Dia, f/2.2 4deg dia FOV)

	60 Mpix	150 Mpix
28cm D	7.4 sqdeg	XXX
36cm D	4.5 sqdeg	11.2 sqdeg

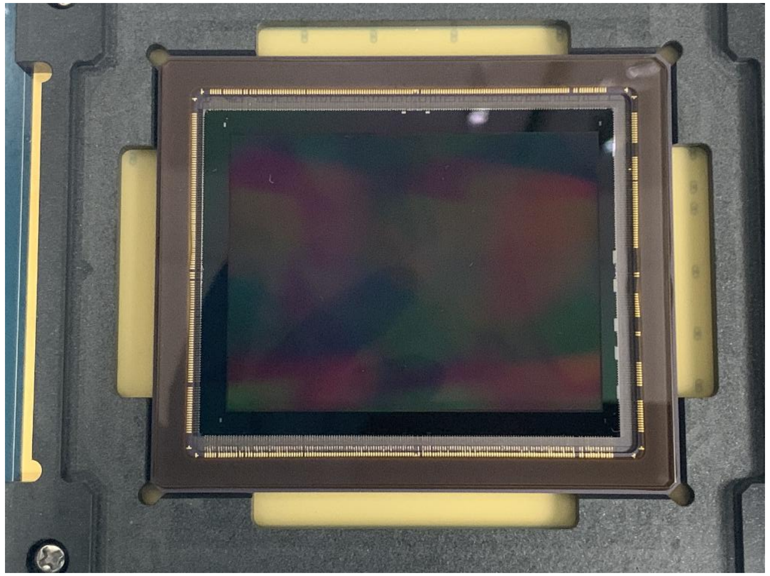
- Recently available consumer focal planes, backside CMOS 3.76um pixels , 1.5e RN
  - 61 Mpix IMX 455 ~87% QE 24*36mm (9520*6340 pixels) 9 Hz
  - 150 Mpix IMX 411 ~87% QE (14208*10656 pix) (40*53mm)

Different ways to use small telescopes

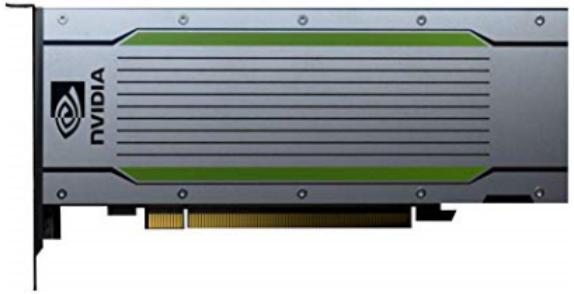
- With low cost small telescopes, the cost is very low but its survey capability doesn't compare larger 1.5m, 2m, or 6~7m counterparts. But the whole idea behind small telescopes is you can afford to buy many perhaps 100's of units.
  - With 240 28cm telescopes $A^*\Omega$ that is 35% of LSST
- Large sky coverage
  - With 240 28cm telescopes cover ~1700 sqdeg at one time. 6 pointings would cover ~10,000sqdeg (π steradians) the sky above 30deg elevation.
- High sensitivity
  - All 240 telescopes have the same 7.4 sqdeg FOV. The outputs of the cameras are added together before further processing. Equal to a 4.2m telescope (in sensitivity) with a 7.4sqdeg FOV.
- Even at N=240 the cost is low compared to a ~2m class telescope. But a large data rate. In a search for interstellar asteroids, we'd want to take images every ~5 seconds. 14 Gpixels *0.2Hz => 165 Tbyte/(8hr)

Basic Components Available

36cm f/2.2 Schmidt
150 Mpix cmos
11.2 sqdeg FOV
21.5 mag limit @
500 sec integ
(100 5 sec exposures)



Sony Imx 411 150Mpix CMOS
Backside Illuminiated 1.5e RN



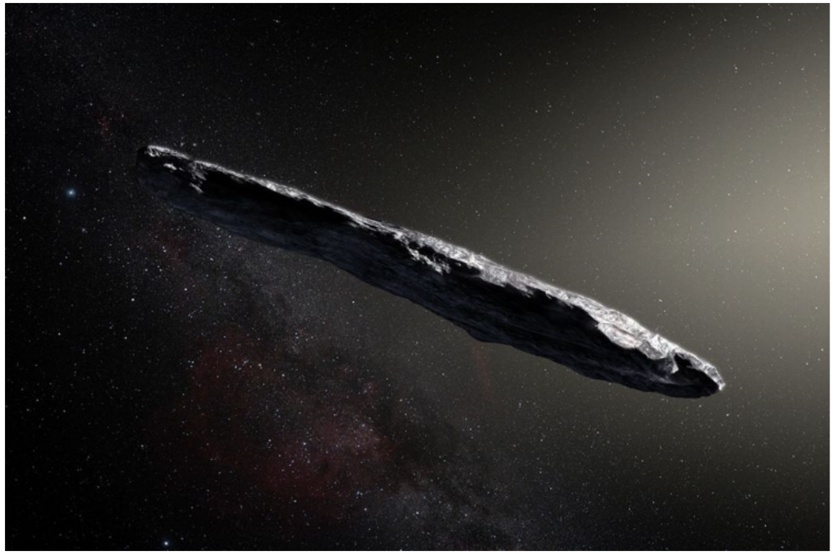
High speed computing at low
Cost T4 GPU, 14 TFLOP (32FP)
At < 3K.

If we have 1 GPU/telescope (240 telescopes) =>
Total computing peak 3.3 petaflops.

Applications (not all compatible with each other)

- Interstellar asteroids
  - Combine synthetic tracking (multiple velocity shift/add) and short exposures (~5 sec exposures) to enable > 10X discovery rate from LSST.
- High frame rates (10 Hz)
  - Occultations of stars by solar system bodies.
  - In galactic plane ~5000 stars with SNR>10 in 0.1 sec per telescope. (7.4 sqdeg, 28cm telescope)
- Optical counter part to transient events (GRB, Grav Waves, FRBs)
  - 1700 sqdeg at a time. 6 pointings cover ~10,000 sqdeg the sky > 30deg elevation (cover 10,000sqdeg to 20.5 mag every 1000 sec)
    - Significant probability the object was observed before the transient alert.
- NEOs search for large > ~100m NEOs, and detection of smaller NEOs that might impact the earth in a few weeks.
- Exoplanets, transits and microlensing (monitor ~ billion background stars for stellar microlensing events, follow with faster cadence for planetary microlensing events)

Interstellar Asteroids (ISO)



- Two possible goals.
  - significantly increase the discovery rate.
  - Find enough so that one of them has an orbit that enables a flyby mission.
- ISO on average move much faster than NEOs
  - Typically 50km/s (5X faster than NEOs)
  - The streaks are ~5X longer, resulting in ~5X lower SNR.
  - Synthetic tracking uses multiple short exposures (> 5X shorter than NEO searches) and performs a shift/add operation.
- If the ISO were 5X closer it's streak would be 25X longer (25X lower SNR) but 5X closer => 25 time brighter.
  - Synthetic tracking enables detection of these fast moving objects ~5X closer, ~125X the search volume.

An array of ~200 small telescopes would have the ~35% of the A*W of LSST, that multiplied by 125 implies a discovery rate approximately ~40X larger.

Photometric Variability (1700 sqdeg at a time)

- We look at two appliations. 1 High speed 10hz photometry, solar system body occultations, 2 monitoring larger number of stars for exoplanets. Microlensing
- A single small telescope 28cm, 7.4 sqdeg FOV, looking in the galactic plane, would see ~5000 stars < 13.4 mag to give SNR~10 in 0.1 sec. In searches for km sized KBO/TNOs via occultations, ~3 telescopes look at the same FOV and look for occultations that occur in all 3 telescopes. With a 240 array or telescopes, we could be looking at ~400,000 stars at one time.
- In exoplanet microlensing, (From J. Yee, A. Gould) one looks for a stellar microlensing event, then increase cadence to potentially detect an exoplanetary microlensing event. The time scale for the stellar microlensing event is slow (days) In 1 hr, the snr~10 limiting mag of a 28cm telescope is ~ 22 mag.
  - In one night, cover 10,000 sqdeg to 22 mag. Monitor ~400 million stars.

Summary

- The introduction of consumer low cost fast (f/2.2) Schmidt telescope and a new generation of large backside CMOS sensors (60Mpix to 150 Mpix) changes the cost/scaling equation for large survey telescopes.
  - A*W/$ potentially > 10X better.
- In addition the CMOS sensors are able to operate at low noise (1.5e) at much higher frame rate than existing mosiac CCD focal planes. (~10Hz) Extends transient astronomy to shorter time scales.
  - Occultations , syn tracking Interstellar objects.
- While this talk has concentrated on large arrays of small telescopes on the ground, similar advantages apply to space based survey instruments.